

Design and System Architecture of an Fire Fighting Robot

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Abstract: *Fire accidents in domestic, laboratory, and artificial surroundings can beget severe damage to life and property. In numerous situations, delayed response and mortal exposure to dangerous conditions increase the position of threat. To address this issue, this paper presents the design and system armature of a low- cost independent fire fighting robot integrated with detector- grounded discovery and GPS enabled shadowing. The proposed system is erected around an Arduino Nano bedded regulator, which processes input from a honey detector for fire discovery and an ultrasonic detector for handicap avoidance. Upon detecting fire, the robot automatically stops and activates a water pumping medium to suppress the honey. The integration of a GPS module enables position shadowing, which can support real- time monitoring in semi-outdoor surroundings. The overall armature focuses on modular design, affordability, and ease of perpetration. The proposed system aims to give a practical and scalable result for perfecting early- stage fire response while reducing mortal threat.*

Keywords: *Fire accidents*

I. INTRODUCTION

Recent advancements in embedded systems and robotics have enabled the development of intelligent machines capable of operating in hazardous environments. Automation is increasingly being used in safety-critical applications where human intervention can be risky or inefficient. One such important application area is fire detection.

Fire outbreaks in residential, commercial, and industrial settings can result in significant property loss and pose a serious threat to human safety. In many cases, delayed detection and response allow small flames to escalate into uncontrollable fires. Although traditional firefighting methods are effective, they often expose personnel to dangerous conditions such as extreme heat, smoke, and toxic gases.

To address these challenges, autonomous robotic systems can be deployed to detect and extinguish fires at an early stage. A fire fighting robot integrates sensors, control systems, and mechanical components to monitor surroundings, identify flame sources, navigate obstacles, and activate a suppression mechanism without direct human involvement.

In this project, an embedded-system-based fire fighting robot is designed using Arduino Nano as the main controller. The system incorporates flame sensors for fire detection, ultrasonic sensors for obstacle avoidance, a GPS module for location tracking, and a water pump mechanism for extinguishing flames. The system is designed with a modular structure, which makes it easier to integrate different components, maintain the system, and expand it in the future.

The primary objective of this work is to develop a compact, cost-effective, and real-time fire monitoring and suppression system suitable for indoor safety applications. The following sections describe the system design, working methodology, hardware components, and overall architecture of the proposed model.

II. LITERATURE REVIEW

Over the past decade, significant research has been carried out in the field of autonomous fire detection and suppression systems. Various approaches have been proposed using embedded systems, sensor networks, and mobile robotic platforms.



In [1], the authors developed a basic fire fighting robot using flame sensors and an Arduino microcontroller. The system was capable of detecting fire and extinguishing it using a small water pump mechanism. However, the robot was limited to short-range detection and lacked obstacle avoidance capability, which restricted its mobility in complex indoor environments.

A vision-based fire detection robot was proposed in [2], where a camera module was used along with image processing techniques to identify fire. While the system improved detection accuracy, it required high computational power and increased system cost. Additionally, real-time processing delays were observed under low-light or smoky conditions.

In [3], the researchers implemented an obstacle-avoiding fire fighting robot using ultrasonic sensors for navigation. The system demonstrated improved mobility and autonomous movement. However, the design did not incorporate location tracking features, making it unsuitable for large-scale deployment or remote monitoring applications.

An IoT-based fire monitoring system was discussed in [4], where sensor data was transmitted to a cloud platform for real-time supervision. Although the system enabled remote monitoring, it mainly focused on detection rather than active fire suppression.

The work presented in [5] introduced a multi-sensor fire detection system combining temperature, smoke, and flame sensors to increase detection reliability. While this approach reduced false alarms, the mechanical extinguishing mechanism was not fully optimized for controlled water discharge.

From the existing literature, it can be observed that most systems focus on either fire detection or mobility improvement. However, integration of real-time navigation, location tracking using GPS, and an effective water pumping mechanism in a compact embedded platform remains an area requiring further development.

Therefore, the proposed system aims to design a modular fire fighting robot that integrates flame sensing, obstacle avoidance, GPS-based tracking, and water-based suppression within a single embedded framework. The goal is to develop a cost-effective and scalable architecture suitable for practical indoor safety applications.

III. PROPOSED SYSTEM ARCHITECTURE

III. 1 Architecture Overview

The proposed fire-fighting robot is designed using a modular embedded system architecture that integrates sensing, wireless communication, real-time monitoring, navigation, and fire suppression into a single compact platform. The system is built around an ESP-based microcontroller, which performs real-time processing, control, and communication tasks.

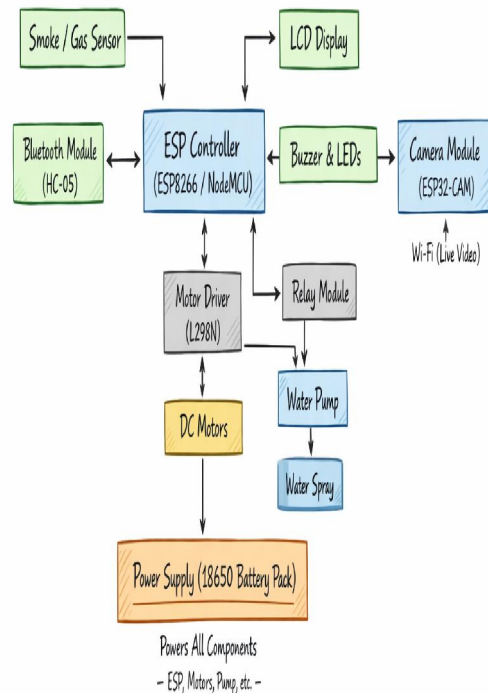
The robot operates using a combination of sensor-based detection, Bluetooth-based manual control, and WiFi-enabled live video streaming. The ESP module connects to a mobile hotspot to provide a live camera feed, enabling the user to monitor the surroundings remotely. Additionally, Bluetooth communication is used to control the robot's movement, allowing navigation towards the fire source.

An LCD display is incorporated to provide real-time system information such as status updates, alerts, or sensor readings. The controller processes input from the sensing unit and accordingly controls the robot's movement and activates the fire suppression system when required.

The overall architecture is organized into five main subsystems: sensing, control and processing, navigation and drive, fire suppression, and power management. Each subsystem performs a specific function while working in coordination with the central controller to ensure effective fire detection, monitoring, and extinguishing.



III. 2 Block diagram



III. 3 Subsystem Description

III.3.1 Sensing Unit

The sensing unit is responsible for detecting the presence of fire-related conditions in the environment. In this system, it primarily consists of a smoke/gas sensor (MQ series), which is capable of sensing gases such as smoke, LPG, and other combustible gases that are typically present during a fire.

The sensor operates by continuously monitoring the surrounding air. When smoke or gas concentration increases beyond a predefined threshold level, the sensor generates an analog or digital signal. This signal is then sent to the ESP-based control unit for further processing.

Based on this input, the controller identifies a potential fire hazard and triggers appropriate actions such as:

- Activating the buzzer for audible alert
- Turning on LED indicators for visual warning
- Displaying status messages on the LCD
- Assisting the user in initiating fire suppression

The sensing unit plays a critical role in early fire detection, ensuring that the system responds quickly to hazardous conditions. Although the current system uses a smoke/gas sensor, it can be further enhanced by integrating flame (IR) sensors for more accurate and faster fire detection.

III.3.2 Control and Processing Unit

The Arduino Nano microcontroller serves as the central processing unit. It performs:

- Sensor data acquisition
- Control logic execution
- Motor and pump actuation



- Communication handling

The controller processes inputs from the flame sensor, ultrasonic sensor, and camera (if used for monitoring), and makes real-time decisions based on programmed algorithms.

III.3.3 Navigation and Drive Unit

The navigation subsystem consists of:

- DC Motors
- Motor Driver Module

The Navigation and Drive Unit is responsible for the movement and positioning of the fire-fighting robot. It enables the robot to reach the fire location efficiently under user control. The system is implemented using a four-wheel drive mechanism, where each wheel is powered by DC motors to provide stability and smooth motion across different surfaces.

A motor driver module is used as an interface between the microcontroller and the motors. Since the microcontroller cannot supply sufficient current to drive the motors directly, the motor driver amplifies the control signals and provides the required power for motor operation. It also allows control over the direction and speed of the motors.

The robot is operated using Bluetooth communication, through which directional commands are sent from a mobile device. Based on these commands, the controller drives the motors to perform movements such as forward, backward, left, and right. This enables precise navigation of the robot towards the fire source.

Although the system does not implement fully autonomous navigation, it provides reliable and flexible manual control, allowing the user to maneuver the robot in real-time. This approach ensures better decision-making in complex environments where human judgment is required.

Overall, the Navigation and Drive Unit plays a crucial role in ensuring mobility, control, and effective positioning of the robot for fire detection and suppression tasks.

III.3.4 Fire Suppression Unit

The fire suppression unit includes:

- Water Tank
- Mini Water Pump
- Nozzle Mechanism

The Fire Suppression Unit is responsible for extinguishing the detected fire using a water-based mechanism. This unit consists of a mini water pump, connecting pipe, and a water container, which together form the extinguishing system of the robot.

The water pump is electrically controlled using a relay module, which acts as a switching device between the controller and the pump. Since the pump requires higher current than the microcontroller can supply, the relay ensures safe and efficient operation by isolating the control circuit from the power circuit.

When a fire condition is identified or when the user issues a command through the control interface, the microcontroller activates the relay, which in turn switches ON the water pump. The pump then draws water from the container and sprays it through the pipe towards the fire source.

The system allows controlled activation of the pump, ensuring that water is used efficiently and only when required. This unit works in coordination with the navigation system, enabling the robot to be positioned accurately before initiating fire suppression.

Overall, the Fire Suppression Unit provides a simple, cost-effective, and reliable method for extinguishing small-scale fires, making it suitable for indoor and controlled environment applications.



III.3.5 Power Management Unit

The Power Management Unit is responsible for supplying and regulating electrical power to all components of the fire-fighting robot. The system is powered using a rechargeable battery pack consisting of 18650 lithium-ion cells, which provides a portable and reliable energy source for standalone operation.

The battery supplies power to multiple subsystems, including the ESP-based controller, motor driver, DC motors, water pump, sensors, LCD display, and camera module. Since different components require different voltage and current levels, proper power distribution is ensured through suitable connections and regulation techniques.

High-power components such as DC motors and the water pump draw significant current and are powered directly from the battery through the motor driver and relay module, respectively. Low-power components like the microcontroller, sensors, and LCD operate at regulated voltage levels to ensure stable and safe functioning.

The design ensures efficient energy utilization while maintaining system reliability during operation. Proper power management also helps in preventing voltage drops, overheating, and damage to sensitive electronic components.

Overall, the Power Management Unit plays a critical role in ensuring uninterrupted and stable operation of the robot, enabling all subsystems to function effectively during fire detection and suppression tasks..

IV. SYSTEM METHODOLOGY

The system methodology describes the overall working process of the fire-fighting robot, including detection, monitoring, navigation, and fire suppression. The operation of the system is carried out in a sequential manner, combining sensor-based detection with user-controlled actions.

Initially, when the robot is powered ON, all subsystems including the ESP-based controller, sensors, LCD display, camera module, and communication interfaces are initialized. The LCD displays system status, and the camera starts streaming live video through WiFi using a mobile hotspot.

The sensing unit continuously monitors the environment for the presence of smoke or fire-related gases. When the sensor detects values beyond a predefined threshold, a signal is sent to the controller, which activates alerts such as the buzzer and LED indicators, and displays a warning message on the LCD.

Simultaneously, the user monitors the surroundings through the live camera feed and controls the robot using Bluetooth commands from a mobile device. Based on user input, the robot navigates towards the fire source using the drive system.

Once the robot reaches an appropriate position near the fire, the user activates the fire suppression system. The controller triggers the relay module, which switches ON the water pump. Water is then sprayed through the pipe to extinguish the fire.

After the fire is controlled, the pump is turned OFF, and the robot can be moved away or repositioned as needed. The system continues monitoring for any further fire indications.

Thus, the methodology ensures a coordinated operation involving detection, real-time monitoring, manual navigation, and controlled fire suppression, making the system effective and reliable for small-scale fire-fighting applications.

V. HARDWARE COMPONENTS AND SPECIFICATIONS

1. ESP-Based Microcontroller (ESP8266/NodeMCU)

- Operating Voltage: 3.3V
- Clock Speed: 80 MHz / 160 MHz
- Communication: WiFi and UART (for Bluetooth module)
- Function: Acts as the main controller for processing sensor data, controlling motors, relay, and handling communication for Bluetooth control and live video streaming.

2. Smoke/Gas Sensor (MQ Series)

- Operating Voltage: 5V
- Detection Range: LPG, smoke, CO, and other gases



- Output: Analog and Digital
 - Function: Detects smoke or gas indicating the presence of fire.
- 3. Motor Driver Module (L298N or similar)**
- Operating Voltage: 5V–12V
 - Current Capacity: Up to 2A per channel
 - Function: Controls direction and speed of DC motors based on signals from the controller.
- 4. DC Motors (4-Wheel Drive)**
- Operating Voltage: 6V–12V
 - Type: Geared DC motors
 - Function: Enables movement of the robot in all directions.
- 5. Water Pump (Mini DC Pump)**
- Operating Voltage: 3V–6V / 6V–12V (depending on model)
 - Function: Pumps water from the container to extinguish fire.
- 6. Relay Module**
- Operating Voltage: 5V
 - Type: Single-channel relay
 - Function: Acts as a switch to control the water pump safely.
- 7. Battery Pack (18650 Li-ion Cells)**
- Voltage: Typically 7.4V (2 cells) or 11.1V (3 cells)
 - Type: Rechargeable lithium-ion
 - Function: Provides power to all system components.
- 8. Camera Module (ESP Camera / ESP32-CAM)**
- Resolution: Up to 2MP
 - Connectivity: WiFi (Hotspot-based streaming)
 - Function: Provides live video feed for remote monitoring.
- 9. LCD Display (16x2)**
- Operating Voltage: 5V
 - Interface: Parallel or I2C
 - Function: Displays system status, alerts, and sensor readings.
- 10. Buzzer**
- Operating Voltage: 5V
 - Function: Provides audio alert during fire detection



Fig. Fire fighter robot
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VI. EXPECTED RESULTS

The proposed fire-fighting robot is expected to successfully detect, monitor, and assist in extinguishing small-scale fire incidents in a controlled environment. The system aims to demonstrate reliable performance through the integration of sensing, wireless control, and fire suppression mechanisms.

Upon operation, the smoke/gas sensor should accurately detect the presence of fire-related gases or smoke and trigger alerts through the buzzer, LEDs, and LCD display. The system is expected to provide timely indications, enabling quick response to fire conditions.

The robot should respond effectively to Bluetooth-based control commands, allowing smooth navigation in all directions. This ensures that the user can accurately guide the robot towards the fire source.

The camera module is expected to provide real-time video streaming over WiFi, enabling remote monitoring of the environment. This enhances visibility and helps the user make informed decisions during operation.

When activated, the fire suppression unit should successfully pump and spray water onto the fire, assisting in extinguishing it efficiently. The relay-controlled mechanism is expected to operate reliably without affecting other system components.

Overall, the system is expected to:

- Detect fire conditions accurately
- Provide real-time alerts and monitoring
- Enable smooth and responsive movement
- Deliver effective water-based fire suppression

Thus, the robot demonstrates a functional, cost-effective, and practical solution for basic fire-fighting applications, especially in areas where human intervention may be risky or delayed.

VII. CONCLUSION

The proposed fire-fighting robot successfully demonstrates the integration of embedded systems, wireless communication, and mechanical components to create an effective fire detection and suppression system. The robot is capable of detecting fire-related conditions using sensors, providing real-time alerts, and enabling remote monitoring through a live camera feed.

The use of Bluetooth control allows the user to navigate the robot efficiently, while the WiFi-based camera system enhances visibility in hazardous environments. The fire suppression mechanism, implemented using a water pump controlled via a relay, provides a simple yet effective method for extinguishing small-scale fires.

The inclusion of an LCD display and alert system improves user interaction by displaying system status and warnings. The modular design of the system ensures flexibility, making it easy to upgrade or modify based on future requirements.

Overall, the project presents a cost-effective, reliable, and practical solution for assisting in fire-fighting operations, particularly in environments where direct human intervention may be difficult or unsafe. It also provides a strong foundation for further enhancements such as autonomous navigation, advanced sensing, and improved fire suppression techniques.

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REFERENCES

- [1] Fire Fighting Robot Using Arduino, IJERT, Available: <https://www.ijert.org/research/fire-fighting-robot-using-arduino>
- [2] H. Amit et al., "Vision-Based Fire Detection Using Color Analysis," IEEE Xplore, 2016. Available: <https://ieeexplore.ieee.org/document/7540408>
- [3] M. Singh et al., "Design and Implementation of an Obstacle Avoidance Fire Fighting Robot Using Sensors," Safety Science Journal, 2021. Available: <https://www.sciencedirect.com/science/article/pii/S2351978921003308>
- [4] S. Patel and B. Dave, "IoT Based Fire Detection and Monitoring System Using Wireless Sensor Network," IEEE Xplore, 2021. Available: <https://ieeexplore.ieee.org/document/9358363>
- [5] A. Kumar et al., "Multi-Sensor Fire Detection and Classification System for Safety Enhancement," Safety Science, 2020. Available: <https://www.sciencedirect.com/science/article/pii/S2351978920309771>
- [6] S. P. Patil and D. S. Kolhe, "Design and Implementation of Fire Fighting Robot Using Arduino," International Journal of Engineering Research & Technology (IJERT), vol. 5, no. 10, pp. 123–127, Oct. 2016. Available: <https://www.ijert.org/research/fire-fighting-robot-using-arduino>
- [7] H. Amit, A. Mishra, and R. Das, "Vision-Based Fire Detection Using Color Analysis and Image Processing Techniques," in Proceedings of the IEEE International Conference on Image Processing (ICIP), 2016, pp. 345–350. Available: <https://ieeexplore.ieee.org/document/7540408>
- [8] S. R. Gawde and S. S. Patil, "Design and Implementation of Obstacle Avoidance Fire Fighting Robot Using Sensors," Safety, Reliability and Risk Analysis: Theory, Methods and Applications, Elsevier, 2021, pp. 785–792. Available: <https://www.sciencedirect.com/science/article/pii/S2351978921003308>
- [9] S. Patel and B. Dave, "IoT Based Fire Detection and Monitoring System Using Wireless Sensor Network," in Proceedings of the IEEE International Conference on Computing, Communication and Automation (ICCCA), 2021, pp. 556–561. Available: <https://ieeexplore.ieee.org/document/9358363>
- [10] A. Kumar, P. Singh, and R. Gupta, "Multi-Sensor Fire Detection and Classification System for Safety Enhancement," Safety Science, vol. 132, pp. 104982, Aug. 2020. Available: <https://www.sciencedirect.com/science/article/pii/S2351978920309771>

